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Using Arduino Kits and Discord to Implement A Fully Remote Laboratory Course During the COVID-19 Pandemic

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Abstract

Laboratory courses were forced to switch to online format during the COVID-19 pandemic, with students losing access to laboratory equipment in on-campus facilities. This paper reports on adapting a senior-level Control and Vibration Laboratory curriculum to enable students to complete exercises remotely, using the Arduino platform and its accessories. The results show that the remote-learning format is a viable and sometimes preferable learning solution based on students' positive feedback. The paper also identified several other online tools and platforms, including Discord and Tinkercad, that contributed to the overall learning experience.

I. Introduction

The COVID-19 pandemic disrupted in-person educational programs worldwide in early 2020, with many programs switching their instructional mode to remote. This shift required educators to develop innovative ways to quickly translate hands-on course components and in-person communication modes to remote mechanisms. In this paper, we report on adapting a Control and Vibration Laboratory curriculum in an undergraduate university mechanical engineering program for using the Arduino platform and its accessories remotely. We redesigned the entire course based on components in the Arduino kit and implemented the updated curriculum such that each student could carry out the experiments remotely using a kit. The instructor-student communication was compensated using a dedicated Discord server, a modern social media platform with asynchronous chatting capabilities.

Before the COVID-19 pandemic, The mechanical engineering senior-level mechatronics laboratory course at University of Maryland, Baltimore County (UMBC) was offered in-person in a dedicated lab classroom. The equipment on top of the workbenches in the classroom includes a NI ELVIS [1], a power supply, an oscillator, and a desktop computer equipped with LabView and Simulink software. Students would form groups and conduct experiments and lab work by using mechatronic devices such as servos and DC motors along with the aforementioned hardware in the lab space. The department would also keep an inventory of peripherals such as jumper wires, sensors, and Arduino Unos. This classic teaching format was forced to change during the pandemic to ensure student and staff safety.

Low-cost microcontrollers such as Arduino and Raspberry Pi have been used in engineering courses for more than one decade [2], [3], [4], [5]. Compared with the prior research about using

Arudino platforms in the classroom, we used the Arduino in a senior-level laboratory course with more in-depth C/C++ programming. Compared to previous work studying the use of Arduinos and other microcontrollers in lab courses, our paper shows the potential of conducting all labs remotely, using a combination of Arduino kits, videos, and a Discord server. While the social distancing measures at the beginning of the pandemic have changed over time, documenting student experiences during this time using a remote approach can inform future implementations that want to deliver similar formats.

In the Spring semester of 2021, the course was delivered fully online. Compared with the in-person teaching, two major challenges introduced by the online lab course format were: (1) no lab equipment access; (2) no in-person office hours. We selected a cost-effective Arduino kit to tackle these challenges to replace the bulky and high-end equipment in the physical lab space. We also decided to incorporate multiple online teaching tools such as Tinkercad and Discord servers into the course to enhance students' learning experience. In general, group work is encouraged in laboratory courses as the students can develop hands-on experience with peers. However, during the pandemic and in the presence of social distancing measures, many uncertainties were present in conducting group work. As such, the labs were re-designed to be completed by individuals.

At the end of the semester, we adapted and deployed a survey (based on earlier work by Recktenwald and Hall [2]) to collect students' feedback and response to the new format of teaching. The main objective of this paper is to summarize the novel teaching setting and provide an overview of the feedback we received from the students. We report on using Arduino microcontrollers to enable remote, distributed, individual, and hands-on lab work for an established senior-level mechanical engineering course curriculum.

Next, we describe our methods, including course components and teaching tools. This is followed by our findings from the student surveys. After discussing these findings and our experience delivering the course during the pandemic, we conclude with ideas for future work. We used a similar format again in Spring 2022. While our focus will remain on the first iteration of the course, We will briefly discuss the differences between these two iterations, as the pandemic situation changed over time, allowing for a hybrid mode of instruction.

II. Methods

This section first introduces the key components of the online teaching tools applied in the course. We also emphasize the programming aspects we incorporated into course activities to suit the course difficulty for senior-level undergraduate students majoring in mechanical engineering.

II.1 Virtual Circuit

The entire course consists of seven labs in total, with students completing the first two labs using the Tinkercad virtual environment and the rest of the four labs with a physical Arduino board. Table 1 provides an overview of the course's lab work. Tinkercad is a free web-based 3D modeling application provided by Autodesk [6]. It provides electronic circuits simulation such as Arduino Uno and plenty of peripheral components, including motors, resistors, potentiometers, breadboards, and more. Our main goal for using Tinkercad was first letting students explore Arduino Uno and its

Lab No.	Title	Description	Hardware
1	Tinkercad – I	LED chaser (virtual circuit)	N/A
2	Tinkercad – II	Serial communication (virtual circuit)	N/A
3	LED chaser	Extend Lab1 with a real Arduino board	LEDs, breadboard, jump wires, potentiometer
4	Ultrasonic ranging	Time-of-flight ranging measurement	HC-SR04, LCD module, potentiometer, buzzer
5	PWM	Pulse-width modulation	Buzzer, thumb joystick
6	Stepper motor	Digital device control	Stepper motor (28BYJ-48), motor driver module (ULN2003), power supply module
7	Servo motor	Servo motor control	Servo motor (SG-90), thumb joystick

Table 1: There were seven labs in total for a 2-credit course. Students carried out the first two labs via virtual circuits. Students then proceeded with the rest of the labs with their own Arduino kits at home. All the hardware components listed in the table are available in the selected kit.

peripherals on their own in a virtual environment without the risk of damaging the actual hardware. Additionally, using Tinkercad first allowed us to create a two-week time window so that the department could deliver the Arduino kits to all the students.

Using the virtual circuit can be advantageous when working on multiple-Arduino projects. For example, in Lab No.2, two Arduino boards are required to build up serial communication among them. If the course was offered in-person, students would carry out the lab in groups as every student would only have one Arduino Uno. However, with the virtual circuit, one can easily set up multiple Arduino boards in the simulation environment (see Fig. 1). In addition, being familiar with Tinkercad provided a backup for students since if a key hardware component in one of the last four labs was damaged and it was impossible to get a replacement in time because of the pandemic, the students could still conduct the lab using the virtual circuit. In brief, Tinkercad was a decent place for the students to start the course.

II.2 Arduino Kit

The Arduino kit we selected has more than 30 components with a cost of around $40. There are a variety of Arduino kits available from online retailers, such as Amazon or Adafruit. We selected the ELEGOO UNO Project Super Starter Kit, as this kit had all the hardware required for our course, including a servo motor, a stepper motor, an ultrasonic distance sensor, an LCD display, a breadboard, a passive buzzer, a thumb joystick, several small LEDs, and a varied selection of jumper wires. While the cost of the kit is low, its components are versatile enough to cover different aspects of mechatronics. It is worth mentioning that the kit comes with a tutorial manual. However, none of the materials were adopted for the course. All the lab work was solely developed and

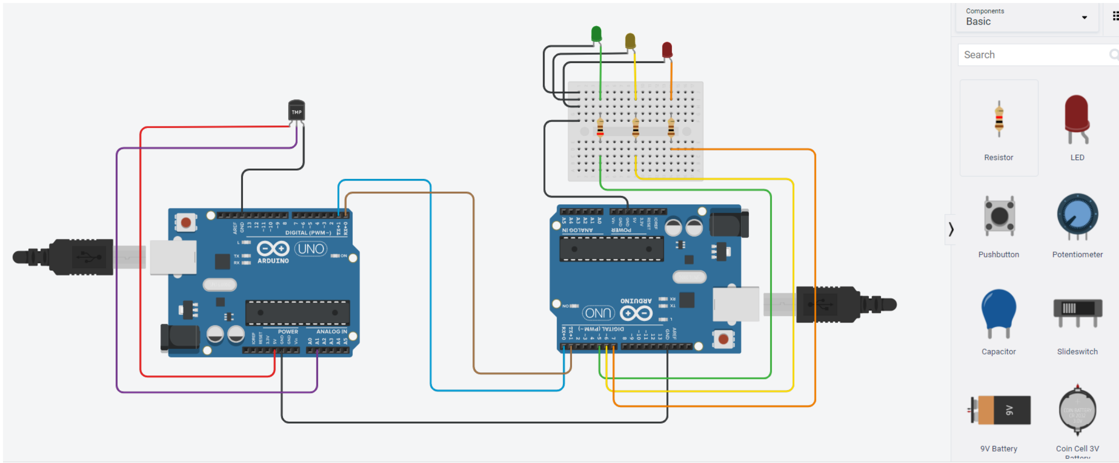


Figure 1: Simulating serial communication between two Arduino boards on Tinkercad: The Arduino Uno on the left is connected to a thermometer. Based on the simulated temperature measurement, it will send messages to the Arduino Uno at the right. And three different LED lights would be turned based on corresponding messages in the communication.

designed by the course instructor (first author).

Compared to the hardware we used before the pandemic, the motors in the kit are more basic in terms of functionality. And the analyzing tools provided by the Arduino IDE are also more primitive than LabView and Simulink. However, the kit is very versatile such that we cover more aspects of mechatronics. For example, there are three different types of motors in the kit: a DC motor, a servo motor, and a stepper motor, which are the most popular motor types in general. The assorted peripherals such as the LCD displays and thumb joysticks are also fun for students to use and can be incorporated into the lab work.

In our implementation, every student in the class purchased their own kit, as the kits are quite affordable compared to other hardware. Literature has shown that letting students acquire their own hardware makes the logistics simple, and gives students a sense of ownership and investment [5]. This feature is even more desirable during the pandemic as students don't have to share any devices with others, minimizing the risk of contracting COVID-19. Furthermore, having this configuration allowed every student to have enough hardware, enabling us to re-design the group projects as individual projects as the latter is more desirable during the pandemic.

II.3 Other Remote Teaching Tools

While the Tinkercad virtual circuits and the Arduino kits enabled the course to be transformed to an online format, we used additional tools to support student instruction and communication. While most of the lab instructions were covered during regular online course lectures, short instructional videos were recorded by the course instructor (first author) to reinforce the key concepts of using the Arduino platform. These videos were presented to the students using the Panopto video streaming platform that our university supports. In addition, all the course materials, including these lecture videos, were available to students for asynchronous access.

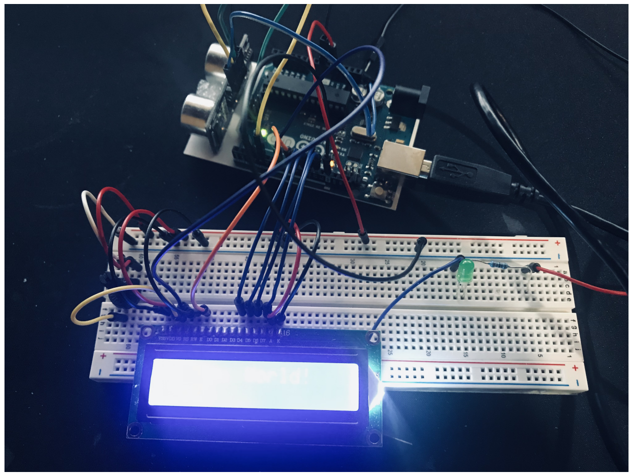


Figure 2: Demonstration of ultrasonic distance sensing lab including a breadboard, ultrasonic distance sensor, an LCD display with some wires. All the components are available in the kit.

In addition, students were invited to a dedicated Discord server in which the instructor and the teaching assistants served as the moderators. Discord is a chat, and social app that is known for its instant messaging and sleek interface [7]. Our goal for using Discord was to facilitate informal interactions between the instructors and the students. There are similar platforms available such as Slack [8]. We choose Discord as it is already popular among the undergraduates in the institution, and thus the students are more likely to be familiar with its interface.

Lastly, short instructional videos were provided by the course instructor (first author). These videos were recorded on Panapto [9], which is the standard platform for asynchronous lecture recording supported by the university. When students had questions that were not straightforward to reply on Discord, the instructor would make a short demo video, so the solution was clearly presented to the entire class. For instance, some students never had any experience with Arudino before this course, and they might have had issues connecting Arudino to their PC. In this case, the instructor would demonstrate how to connect Arduino to PC with all the system settings on Arduino IDE. The entire process was recorded to a Panapto video and shared with the class.

Overall, the combination of remote learning tools was more effective than expected. For example, for Lab 4, one student had issues with the LCD display. The student then asked for help on the Discord server. Before the course instructor could respond, multiple students provided their own insights about possible issues. Then the instructor joined the conversation for troubleshooting. Eventually, the LCD display was diagnosed to be broken. The student then performed Lab 4 virtually as all the components were available on Tinkercad. The entire process was documented in the student's lab report.

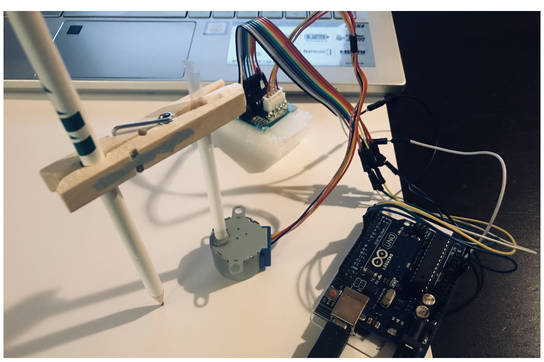
II.4 Lab Outlines

Lab 1 had two parts. In the first part, students were asked to familiarize themselves with Tinkercad on their own and record a demo video introducing Tinkercad as there is no user manual for this platform. In part 2, students were asked to build an LED chaser on Tinkercad utilizing the knowledge they had just taught themselves. In Lab 2, students were instructed to build a temperate sensing module between two Arduinos. A snippet of Lab 2 is shown in Fig. 1. Once the students were comfortable with the Arudino environment and refreshed their memory about circuitry, they built up the LED chaser on the actual Arduino Uno in Lab 3. This particular setup gave students a slow start as the entire course was online. The goal is to minimize the learning curve and prepare students for the intense lab for the rest of the semester.

Lab 4 emphasized range sensing utilizing an ultrasonic distance sensor. A similar lab existed in the curriculum before the pandemic as position sensing is crucial for motion control. In the in-person setup (i.e., prior iterations of the course), students would design a PID controller to balance a cantilever beam where the proportional term is coming from the range sensing. However, during the pandemic, the cantilever beam was not available to students. Hence, the lab was more focused on sensory measurements. The Arudino setup for Lab 4 is shown in Fig. 2.

Lab 5 focused on pulse-width modulation (PWM), which uses the digital-to-analog converter (DAC) on the Arduino platform. Students were asked to compare voice output from a buzzer when it is connected to a PWM-supported digital pin versus a non-PWM-supported digital pin.

Lab 6 and Lab 7 were about motor control. Students were asked to explore a stepper motor and a servo motor in Lab 6 and Lab 7, respectively. Students were asked to build a simple marking tool with the material available in their home lab and then mark the angular movement for an experiment. Then they would use this tool, a printable protractor, and a timer to verify the motor speed controller they programmed. The tool can be simple as shown in Fig. 3. Clearly, this was a temporary solution during the pandemic. Later in Spring 2022, the marking tools were 3D printed and provided to students for a better experimental result.



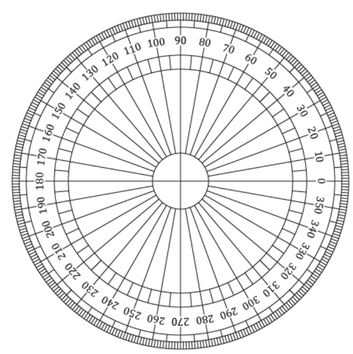


Figure 3: Set up for Lab 6. Students were asked to build a simple tool (shown on the left) to mark the angular motion of the stepper motor. The motion can be marked on the printable protractor (shown on the right).

II.5 Programming & Sensor Calibration

The Arduino platform has become very popular in college-level education in the past decade, and most of the literature reports on its use by first-year or second-year engineering students (e.g., [2], [3], [4], [10]). Our course is senior-level; as such the students are expected to have advanced knowledge about programming and control theory. They may even come across the Arduino platform in their senior capstone projects. Hence, we raised the complexity of the programming part in this course. Instead of using open-source libraries offered by the Arduino community, the students were asked to write the code from scratch for most of their lab work. Also, sensor calibration was added to the curriculum to enhance the hands-on experience.

For instance, the ultrasonic sensor is the most basic type of time-of-flight ranging sensor, and the distance measurement can be found by a simple equation with the speed of sound. Using the concept of time-of-flight, students were asked to make further adjustments on the maximum measuring range. Students were asked to show full, and half-step drives for the stepper motor and build a user-defined function to control motor speed. While the aforementioned functionalities are common, students were asked to reach the goals without using any existing libraries. In other words, students created the libraries on their own. In the servo motor lab, the students were asked to test the servo to observe the motor performance and then compare their results with the datasheet provided by the manufacturer.

These steps to increase the difficulty in programming and sensor calibration are independent of virtual learning and can be applied in the future, whether the course is conducted in-person or online.

II.6 Course Assessment using Student Surveys

We deployed a survey consisting of several components to elicit students' feedback about their experiences with the course during the remote instruction mode and their perceptions about the teaching tools used. These included 5 Likert scale questions asking students about how the course impacted their mechanical engineering interests, knowledge, and skills (see Table 2). Five Likert scale questions asking students about how helpful they found specific online learning components (e.g., Arudino kit, Tinkercad, etc.) and the result is shown in Table 3. Additionally, there were three open-ended qualitative questions about any comments about each of the main specific tools used (Arduino kit, Tinkercad, and Discord server), and three open-ended questions about the overall experience with the course, the online learning experience, and any additional feedback for the instructor. Finally, we included 5 Likert questions asking students how helpful they found each of five remote teaching tools (Arduino kits, Tinkercad, Discord server, Pantopo instructional videos, lecture slides, and sample codes).

III. Assessment Results

The course roster had 100 senior students registered in the 2021 Spring semester, and 59 students (11 of them identifying as female) participated in the survey voluntarily without receiving any incentives. The outcomes of the survey are shown in Table 2 and Table 3. The items in Table 2 are related to the mechanical engineering profession, and Table 3 shows students' responses regarding the online learning components.

Items No. 1 through No. 5 indicate student interest in mechanical engineering and programming as academic disciplines. The survey outcome indicates that the course had a positive impact on student interest in mechanical engineering and programming. The positive fraction (i.e., the

No.	Title	▲(%)	★(%)	■(%)	●(%)	▼(%)
1	The hands-on experience in this class has caused my interest in mechanical engineering has ...	19.0	60.3	17.2	3.4	0
2	Working with the Arduino microcontroller has caused my interest in programming to ...	32.2	49.2	11.9	5.1	1.7
3	The prototyping and sensor exercises experience in this class has caused my motivation for school work to ...	27.1	44.1	22	5.1	1.7
4	The lab work, such as programming and prototyping in this class has caused my practical knowledge of the engineering profession to ...	23.7	64.4	11.9	0	0
5	The lab work, such as programming and prototyping at home has caused my problem-solving skills ...	20.3	69.5	10.2	0	0

Table 2: Survey results regarding academic disciplines.The ▲, ★, ■, ●, and ▼ symbols indicate "Increase a lot", "Increase", "Not change", "Decrease" and "Decrease a lot", respectively.

two columns under ▲ and ★ in Table 2) for all of items are above 70%. Moreover, a large majority of students (89 percent) indicated that the class increased their understanding of engineering professions. Specifically, responses to item no. 5 indicate that almost 90 percent of students taking the survey agree that their problem-solving skills have increased.

Item No. 6 to item No. 10 focus on students' experience with the remote learning tools, including the Arduino kit, Tinkercad, and the Discord server, which are the new elements in the online learning environment. In particular, the survey shows that students appreciated using Arudino kits in the course because of the hands-on experience of using a "real" microcontroller and the related components in a fully online course. Overall, more than 80 percent of the students agree that they have learned a lot from this course without any in-person component (item No. 10).

Sample student qualitative feedback regarding using the Arduino kit are shown as follows:

> *"The kit was really exciting to get and play around with. I like that this is something that I can take away from the course that I can use on my own projects in the future."*

> *"Without sounding crazy, I have bought so many other sensor kits and stuff just because I have gotten so into this Arduino stuff since this class."*

> *"The Arduino kit looks good and is very satisfying to use. Others have had issues with components breaking but I have not had this issue."*

Students also had positive feedback about using Tinkercad. The open-ended sample comments in response to Tinkercad (item No. 7) are shown as follows:

> *"I liked being able to test out my code and circuitry without having to worry about ruining lab equipment."*

No.	Title	▲(%)	★(%)	■(%)	●(%)	▼(%)
6	I found the Arduino kit helpful in learning about programming at home.	74.1	22.4	3.4	0	0
7	I found the Tinkercad platform helpful for learning about Arduino programming at home	59.3	33.9	5.1	0	1.7
8	I found the Discord server provided by the instructor helpful in finding solutions to technical problems I encountered.	52.5	25.4	18.6	1.7	1.7
9	Overall, this class has increased my interest in mechanical engineering or computer science.	30.5	54.2	11.9	0	3.4
10	Without any in-person classes, I am still learning a lot from the lab work and the materials provided by the instructor	39	45.8	10.2	3.4	1.7

Table 3: Survey results regarding online learning tools applied in the course. The ▲, ★, ■, ●, and ▼ symbols indicate "Strongly agree", "Agree", "Neutral", "Disagree" and "Strongly disagree", respectively.

> *"I liked it over the Arduino, because everything is clearly labeled, and you can do the same things. It was also quicker to set up and use than an actual Arduino."*
>
> *"Tinkercad was the best part of prototyping because it allowed for full testing and coding for our actual board. it allowed for wiring and code to be tested more efficiently."*

The Discord server provided a casual space to the students and the instructor as well. The instructor (first author) did offer office hours via web conferencing. However, most students would not attend the office hours if they had quick questions in the middle of working on the labs. Instead, they would post their questions on the Discord server. Furthermore, classmates who experienced similar issues would help their fellow students. So the students were virtually interacting and collaborating with the class through using the Discord server. Specifically, sample student comments on the Discord server included:

> *"Discord server is a great idea for students to feel at ease with communicating. It is difficult to say why, but the teachers seem more approachable in that type of setting and it makes it easier to ask for help."*
>
> *"Easier to get a quicker response from the professor and see everyone's questions get answered."*
>
> *"The discord server was incredibly useful in both causally engaging with the professor and students as well as in receiving answers to questions. I would strongly recommend using it in the future."*

Lastly, the survey asked students about all the learning tools provided by the instructor, and the outcome is shown in Fig. 4. Students agreed that all the tools enhanced the remote learning experience. Specifically, the Arduino kit, Tinkercad, and the sample codes received the most acknowledgment.

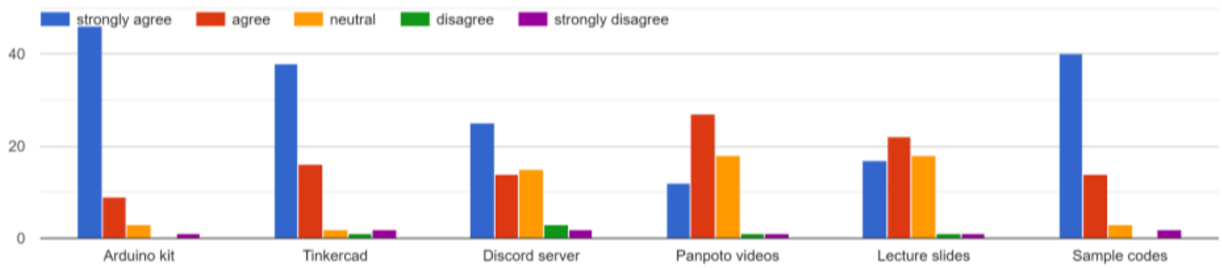


Figure 4: Survey question: "I found each of the following tools helpful for learning about Arduino programming at home." The horizontal axis indicates different tools provided by the instructor and the vertical axis indicates the number of the students. Note that the Panapto videos refer to the short instructional videos recorded by the instructor.

IV. Discussion & Future Plans

Based on the survey result, we successfully transformed the in-person laboratory course into a fully online format. We were still able to cover similar subjects as were taught in the in-person format. The students turned their homes or private studios into their own lab space and conducted experiments by themselves. The encouraging reviews we have received from the students inspire us to keep exploring these innovative forms of pedagogy in the future.

As we were writing the final draft of this paper, the Omicron variant was surging in the U.S. and worldwide, making us consider hybrid options for the Spring 2022 version of the course. We decided to offer the course in hybrid mode, with students attending the lectures in-person and students doing the lab work individually using the same Arduino kit and the online teaching tools mentioned in this paper. The same lab structure was adapted to a hybrid teaching format easily. For example, for Lab 2, the serial communication was completely simulated on the Tinkercad in Spring 2021. However, in the ongoing Spring 2022, this lab was carried out with actual Arduino boards while Tinkercad was still used as a troubleshooting platform. Another change with using the actual circuit was that a tilt sensor in the kit replaced the temperature sensor. As these examples show, the lab design can be very versatile because of the various components included in the kit.

The fact that students owned the hardware simplified the logistics significantly. The department no longer needed to maintain an inventory list for all the small components. In general, modern lab equipment has a wide range of adaptability in terms of peripheral connections, including a variety of microcontrollers. Hence, the Arduino kits will still be useful when the class is back to an in-person format.

V. Conclusion

The COVID-19 pandemic has required educators to adapt their instruction modes, course formats, and delivery style to accommodate public health measures, such as social distancing. In this paper, we described how we used Arduino-based kits, Tinkercad virtual circuits, original instructional videos, and a Discord server to conduct a senior undergraduate lab-based course in mechanical engineering remotely. We used a survey to elicit students' feedback on the new tools and mode of instruction. We found that the majority of students found the experience valuable and indicated that it increased both their skills and interest in the topics covered in the course.

While in the future, the need for fully conducting the course remotely is likely to change, some of the innovations, including the use of Arduino-based kits and the Discord server, proved valuable even with in-person or hybrid teaching modes. In the future, we plan to continue building on our current work to explore new ways that students can engage with programming and engineering practices regardless of the mode of instruction.

VI. Acknowledgement

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References

[1] "Ni elvis," https://www.ni.com/en-us/shop/hardware/products/ni-elvis.html.

[2] G. Recktenwald and D. Hall, "Using arduino as a platform for programming, design and measurement in a freshman engineering course," in *ASEE Annual Conference & Exposition*, no. 10.18260/1-2–18720, 2011.

[3] W. W. Walter and T. G. Southerton, "Teaching robotics by building autonomous mobile robots using the arduino," in *ASEE Annual Conference & Exposition*, no. 10.18260/1-2–23103, 2014, https://peer.asee.org/23103.

[4] M. D. Bedillion, K. H. Muci-Kuchler, and W. M. Nikshi, "An arduino-based hardware platform for a mechanical engineering sophomore design course," in *ASEE Annual Conference & Exposition*, no. 10.18260/1-2–29774, 2018, https://peer.asee.org/29774.

[5] M. Daugherity, "Introducing programming and problem solving with arduino-based laboratories," in *2019 ASEE Annual Conference & Exposition*, no. 10.18260/1-2–33016, 2019, https://strategy.asee.org/33016.

[6] "Tinkercad," https://www.tinkercad.com/.

[7] "Discord," https://discord.com/.

[8] "Slack," https://slack.com/.

[9] "Panapto," https://www.panopto.com/.

[10] W. Rosen, Y. Ertekin, and M. E. Carr, "An autonomous arduino-based racecar for first-year engineering technology students," in *ASEE Annual Conference & Exposition*, 2014.